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EXPLORER XXIX (THE GEODETIC EXPLORER)

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Explorer XXIX in orbit (artist's conception).

Early in the Space Age, the beeps of a satellite signalling its whereabouts to earth sent surprised scientists back to their desks to recheck their figures. This was painstaking work for the figures filled many fat volumes. The figures turned out to be correct.

What they showed was a pattern of irregularities in the orbit of the Vanguard I satellite.

The researchers concluded that such fluctuations must be due to differences from place to place in the force of earth's gravity. They also knew that differences in gravity pull are associated with uneven distribution of earth's mass—the material making up the earth.

Essentially what the figures told the scientists is that the earth's mass is so distributed that our

planet tends to be pear-shaped. The earth, like a pear, is very slightly broader at the bottom (south) than at the top (north). Such information has important significance for scientists studying the structure of the earth.

Since this beginning, satellites have enabled the science of geodesy to enter a new era. Geodesy refers to the mathematical determinations of—

- the earth's size, shape, and mass
- variations in earth's gravity
- distances between and locations of points on earth.

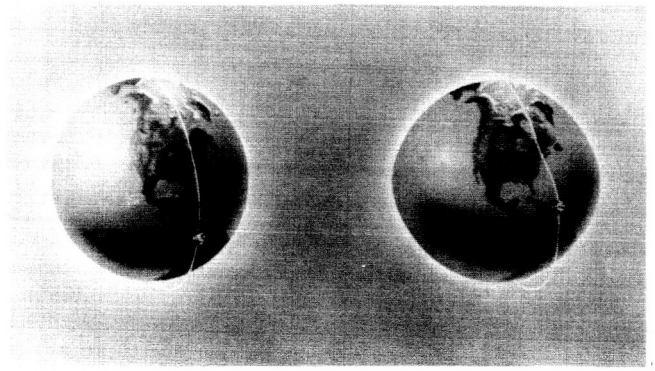
Geodesists using satellites have already acquired a wealth of new information about the earth, as you will see later on. With the launch of Explorer XXIX, the Geodetic Explorer satellite, on November 6, 1965, the United States embarked upon one of its most extensive geodetic projects. It is one of several satellites in the United States National Geodetic Satellite Program, designed to reap new knowledge about our planet's structure, origin, and history. Improved global maps which the program is making possible can aid navigation. Accurate maps and increased knowledge about earth's irregular gravitational field can contribute to precision in launch, guidance, and tracking of rockets and spacecraft.

SATELLITE GEODESY ADDS TO KNOWLEDGE ABOUT OUR PLANET

Satellites are providing man with a treasure chest of new geodetic knowledge. Geodesists using satellites have found that although reasonably good maps of the Pacific Ocean exist, some remote islands are actually miles from their charted positions.

Today, geodesists can calculate distances between points thousands of miles apart to within several hundred feet of the actual distance. With satellites, they look forward to refinements that will enable them to calculate such distances to within 40 feet.

Satellites have shown that in addition to its slight pear shape, the earth has an equator that is elliptical rather than circular. They have revealed still other irregularities. Among these are



Measurements of up and down movements in a satellite's orbit can help show elevations and depressions (right). If the earth were perfectly round, the satellite's orbit would be a smooth ellipse as at left. (Earth's equatorial bulge and the orbital variation are exaggerated.)

four high and five low areas. The approximate locations of the highs are in the:

- (1) Pacific Ocean near Okinawa
- (2) Pacific Ocean west of Peru
- (3) Indian Ocean midway between Africa and Australia, and
- (4) Atlantic Ocean just east of Iceland.

The lows are in the:

- (1) Antarctic,
- (2) Atlantic Ocean east of Charleston, South Carolina,
- (3) Indian Ocean south of India
- (4) Pacific south of the Aleutian Island chain of Alaska, and
- (5) Pacific Ocean midway between California and Hawaii.

Each of the lows and highs covers thousands of square miles of surface area. The difference, however, between the highest and the lowest points may be only a few hundred feet.

As a result, the irregularities can not be seen by a man in space. Nevertheless, they cause a satellite's orbit to rise above and fall below the perfectly elliptical path that it would otherwise follow.

The irregularities are not surface features such as mountains, valleys, continental and other land masses, river and lake beds, and ocean basins. These features result for the most part from erosion by water or from dropping or uplifting of the surface due to stresses inside of the earth. (The stresses are usually associated with our planet's presumed molten core.)

SOME GEODETIC TERMS

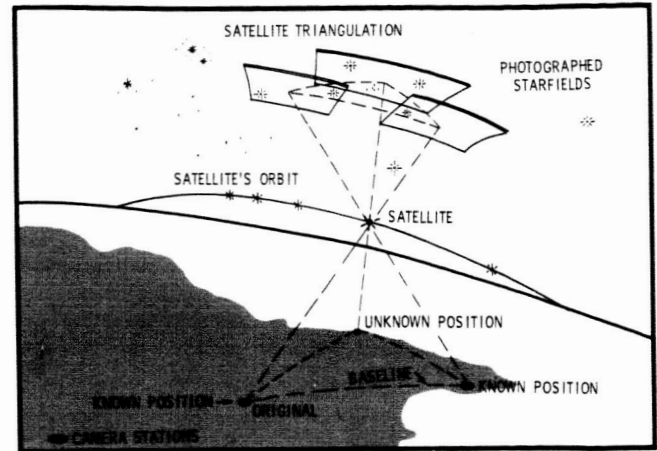
When geodesists discuss irregularities, they refer to them as distortions in the *geoid*. The geoid is the theoretical form or shape they assume to represent the earth's true shape.

The geoid may be thought of as an earth entirely covered by water. However, this imaginary earth is not like a smooth ball.

In places, the waters are drawn down several hundred feet below mean sea level. In other places, the water level is higher than mean sea level.

The irregularities in the geoid are due to differences from place to place in the strength of earth's gravity. Such variations are associated with uneven distribution of the earth's mass.

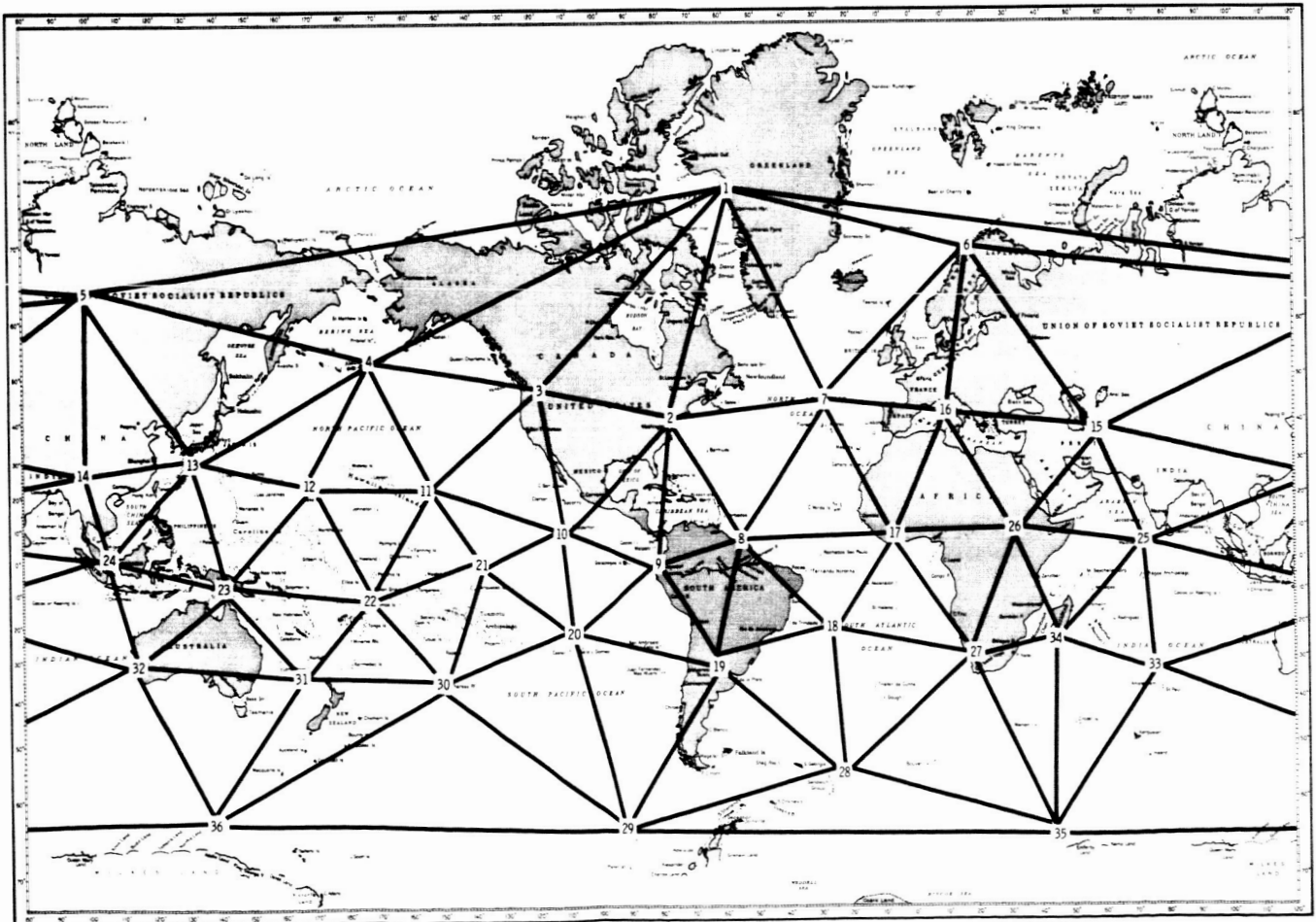
The differences in gravitational force are minute, somewhat more or less than one-thousandth of one percent. But they are sufficient to



Geometric geodesy by photographing satellite against star fields. Note series of triangles drawn by geodesists to calculate coordinates of unknown positions by triangulation (see text).

cause a satellite to move up and down as much as hundreds of feet above and below a truly elliptical path. This is how satellites are providing man with an opportunity to acquire, more rapidly

One purpose of the U.S. National Geodetic Satellite Program is to develop a global network of triangles for accurate determination of locations of places and distances between places. Control points (see text) are numbered.



than by other methods, an overall picture of earth's gravity and enabling him to determine the contours of the geoid.

Measuring variations in earth's gravity is termed *gravimetric* or *dynamic* geodesy. Such information not only advances scientific knowledge about our planet but also contributes to accuracy in launch and guidance of spacecraft.

Geometric geodesy is that branch of geodesy concerned with accurate mapping of the earth. Fundamental to geometric geodesy is *triangulation*. *Triangulation* is based on the mathematical principle that all elements of a triangle can be defined when at least three are known, of which one is a linear quantity, such as a side.

Calculations are based on the fact that any two ground stations and the satellite's position at a particular time form a plane triangle in space. Geodesists then draw other triangles and work from triangle to triangle to obtain the information they need (see illustration).

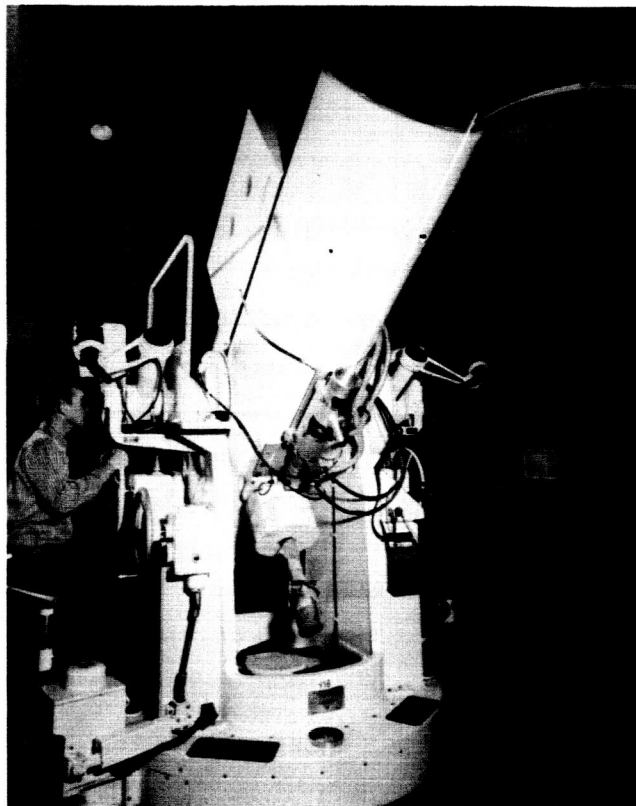
To geodesists, there are two kinds of places: *known* and *unknown*. Known sites are those whose coordinates (locations in terms of accurate longitude and latitude) have been pin-pointed. Unknown sites are those whose exact positions are as yet undetermined.

The *baseline* is the precisely measured distance between two known ground points. When the satellite's angles of elevation relative to the points are determined, the line can serve as a basis for measuring other lines or distances.

Control points are known locations or sites at the points of triangles which form a triangulation network. One purpose of the National Geodetic Satellite Program is to cover the earth with a single coordinated triangulation network (see map). Such a network would increase accuracy in finding the coordinates of any point on earth as well as distances between points.

GEODETIC EQUIPMENT OF EXPLORER XXIX

Many United States satellites, primarily designed for other purposes, have contributed to geodetic knowledge. In addition, several United States satellites have been launched with geodesy a major objective. Among the latter are: ANNA



Laser tracking device in action. Note pencil-thin beam of light. The laser is mounted on an optical tracking telescope.

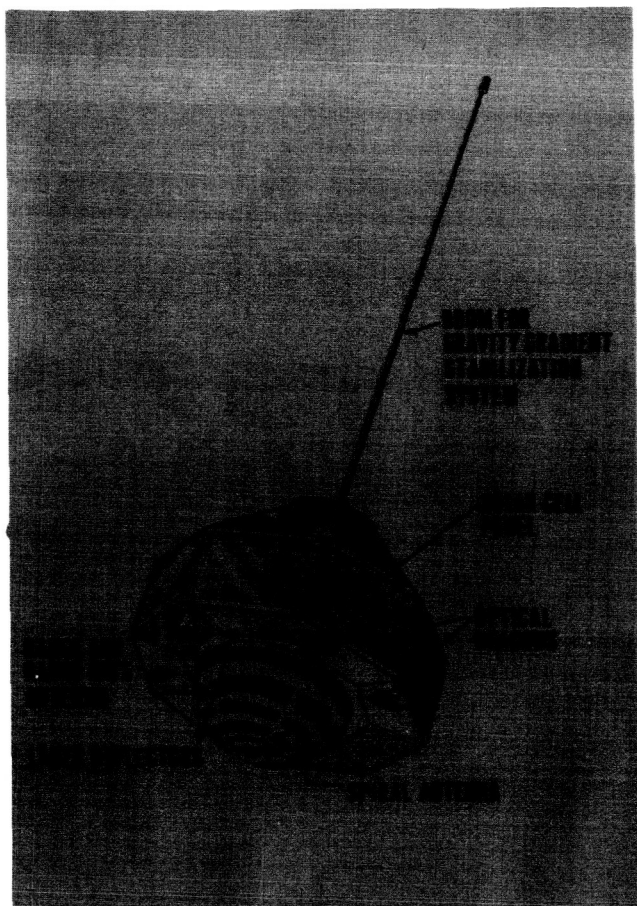
(for Army, Navy, NASA, and Air Force), NASA's Explorers XXII and XXVII, the Army's SECOR (for Sequential Collation of Range), and the Navy's navigation satellites.

Explorer XXIX employs five geodetic measuring (or information gathering) systems, one or more of which have been used on each of these earlier satellites. Scientists believe that accuracy and completeness of overall results can be improved by cross-checking data from the different systems on this one satellite. Moreover, the different systems can make up for each other's shortcomings. For example, the optical beacon system (see below) cannot be used successfully in daylight while radio techniques can.

Explorer XXIX geodetic equipment includes:

- 1) Optical Beacons (high powered flashing lights). The satellite is equipped with a system timed to flash four 670-watt bulbs at planned times.

Telescopic cameras on earth photograph the flashes against a background of stars. Using star charts as guides, geodesists determine the satel-



Artist's drawing of the Geodetic Explorer XXIX with call-outs designating principal parts.

lite's position in space and angle of elevation from each station. The satellite is usually photographed simultaneously by three camera stations. Two are at known locations. The third is unknown. (See illustration.)

2) Laser. Laser stand for *light amplification by stimulated emission of radiation*.

Ordinary light is a mixture of wave lengths, or colors, and scatters in all directions. Laser light is uniform in wave length (one color) and remains narrow and intense over long distances.

Explorer XXIX is equipped with quartz prisms so constructed that the laser beam striking them is reflected back to its source. At the ground station, the time taken for the beam's round trip and the direction from which it comes provide the bases for determining range and angle.

3) Radio Range. Explorer XXIX equipment for this geodetic technique is a transponder. A transponder is a kind of radio that, upon receiving

a prearranged radio signal, responds by transmitting its own signal to the sender.

In the radio range system, the ground stations transmit in rapid sequence to the satellite. By analyzing the returning radio signals, experimenters at each ground station can determine precisely how far away the satellite is.

4) Doppler Beacon. This system is based on the fact that there is a definite relationship between a satellite's movements and the Doppler shift of radio signals received from the satellite.

The Doppler shift is named for Johann Doppler of Prague (Czechoslovakia) who first described it in 1842. The shift is like the changing frequency, or pitch, of the whistle of a train as it approaches and passes a hearer. Actually, the whistle's sound has not changed, just how it is heard.

What has happened is that sound waves pile up, in effect, in the direction of the hearer as the train approaches. They stretch out from the hearer's standpoint as the train speeds away.

Similarly, the frequency of radio waves reaching the ground from a moving satellite changes although the satellite transmits at the same frequency

A feature of this system is that radio transmission is one way rather than two ways. The transmissions are from the satellite to the ground station only.

Satellite tracking experts can now compute a satellite's orbit by analyzing a sufficient body of Doppler data. Conversely, when they know the orbit of a satellite, they can use Doppler data to calculate the location of an unknown receiving site.

The primary objective of the Doppler Beacon experiment of Explorer XXIX, however, is gravimetric rather than geometric. If the geoid were a perfect sphere, it would cause a satellite's orbit to resemble a smooth curve called an ellipse. The geoid, however, is not a perfect sphere.

As a result, a satellite's orbit moves above and below a mathematically perfect ellipse. This causes the Doppler shift of the satellite's radio signals to differ from what it would be if the satellite's orbit were uniformly elliptical. Analyses

of these differences indicate elevations and depressions in the geoid.

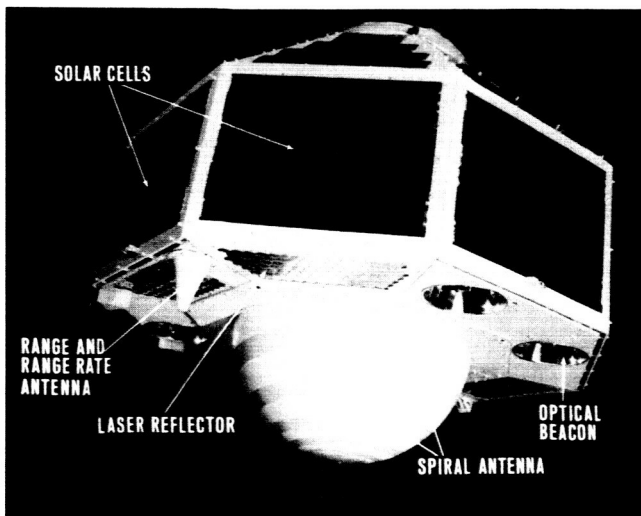
5) Range and Range Rate. The range and range rate system of NASA is being employed primarily to supplement data from other tracking techniques used in the Explorer XXIX experiment. A single ground station is employed to acquire information relative to the distance of the satellite (range) and speed relative to the station (range rate). The system combines features of the Radio Range and Doppler Beacon systems noted in 3 and 4 above.

SPACECRAFT DESCRIPTION

The 385-pound Geodetic Explorer has a maximum diameter of $4\frac{1}{3}$ feet and is $3\frac{3}{4}$ feet high. Extending from the top is an approximately 60-foot-long boom, or rod.

The satellite has three separate systems for generating electricity. Each system powers a specific group of instruments. The separate systems prevent interference of one group of instruments with another's requirements. Each electrical generating system consists of a bank of solar cells and a nickel-cadmium rechargeable storage battery. Solar cells are devices that convert sunlight to electricity for running electrical equipment. The solar cells cover the sides and upper parts of the satellite while the batteries are housed inside of the craft, along with radio and other electronic equipment.

Close-up side view of Explorer XXIX. Note call-outs.



The flat side of the satellite, which is intended to face earth, holds the optical beacons (high powered flashing lights), the laser reflectors, an antenna shaped like a small cone for the range and range-rate system, and, for all other radio requirements, a spiral antenna fused to a hemisphere. The boom projecting from the other side of the satellite helps keep the flat side facing the earth. It is part of the gravity gradient stabilization system.

GRAVITY GRADIENT STABILIZATION SYSTEM

The gravity gradient stabilization system provides a means to keep one side of a satellite facing earth without complex electronic and mechanical equipment. The system functions in accordance with a physical phenomenon; i.e., an earth-orbiting object, with weight concentrated at both ends, tends to point to the center of the earth.

When its boom, with the special weight at the far end, is extended from the main satellite body, the Geodetic Explorer is just such an object. Ground command extended the boom when the proper side of the rotating satellite faced earth. This is the side on which the flashing lights, laser reflectors, and radio antennas are located.

GROUND FACILITIES

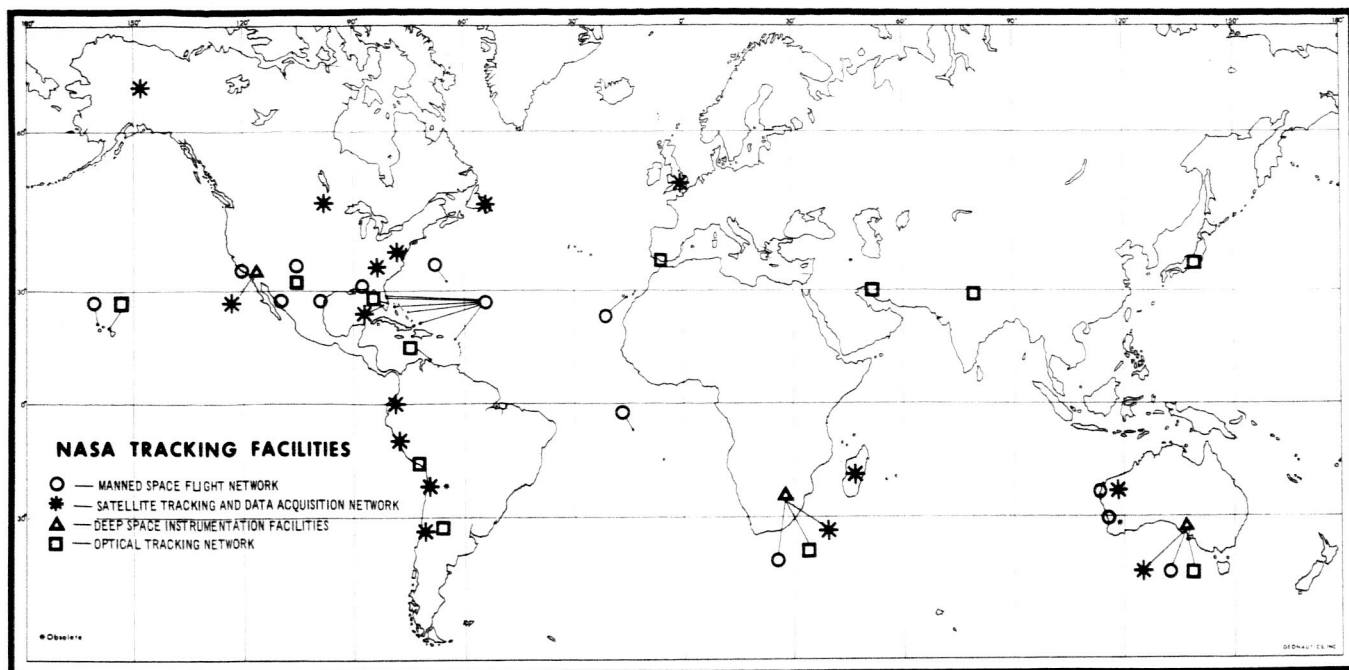
The Explorer XXIX experiment employs surface facilities already established for other purposes. Principal facilities used or being considered for use include:

1) NASA's Satellite Tracking and Data Acquisition Network (STADAN) which uses both radio and optical tracking equipment. Stations are fixed.

2) NASA's range and range-rate system consisting of fixed equipment.

3) NASA's Deep Space Network (DSN), the giant antennas and associated equipment that have been used to support unmanned lunar and interplanetary missions.

4) NASA's Manned Space Flight Network, used primarily for support of manned missions into space. It is made up of both fixed and transportable stations.



NASA and Smithsonian Astrophysical Observatory tracking facilities.

5) The United States Navy Tranet fixed and transportable installations, which are used primarily in conjunction with the Navy's navigation satellite system. Transportable stations enable geodesists to extend the limits of their surveys much farther than if the stations were fixed.

6) The huge fixed high-precision cameras of the global Baker-Nunn network of the Smithsonian Astrophysical Observatory.

7) Transportable SECOR ground facilities of the United States Army.

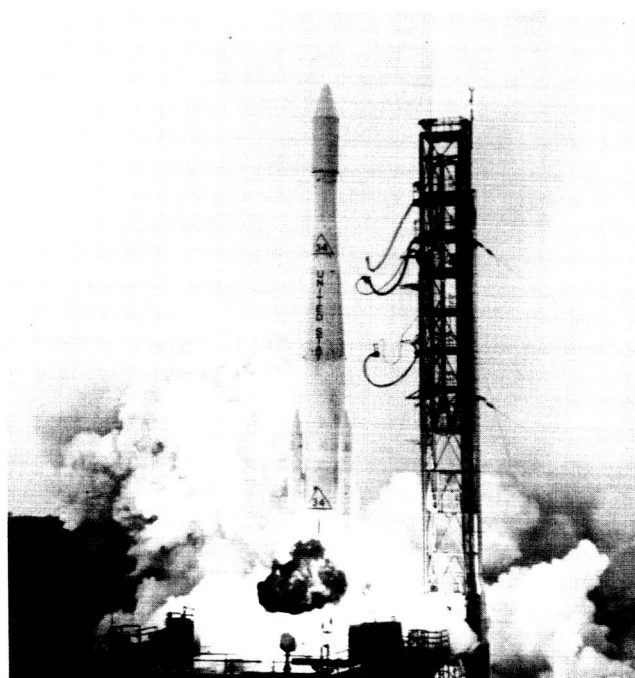
8) Transportable camera facilities of the Coast and Geodetic Survey (Department of Commerce).

9) Transportable geodetic stellar camera facilities of the United States Air Force.

10) Observation stations of other nations.

Among nations with participating scientists or organizations are: Finland, France, Sweden, Greece, The Netherlands, Switzerland, United Kingdom, and the Federal Republic of Germany. Principal participating organizations in the United States are NASA, the Department of Defense, and the Department of Commerce.

Thrust-Augmented Delta (TAD) launches Explorer XXIX.



WORLD-WIDE PARTICIPATION

Scientists, both in the United States and abroad, are participating in the Explorer XXIX experiment and other phases of the U.S. National Geodetic Satellite Program. Data obtained will be made available to qualified scientists throughout the world.